CHAPTER 23 (Odd)

1. a. left: $d_1 = \frac{3}{16}'' = 0.1875''$, $d_2 = 1''$

$$\begin{aligned}\text{Value} &= 10^3 \times 10^{0.1875''/1''}\\ &= 10^3 \times 1.54\\ &= \mathbf{1.54\ kHz}\end{aligned}$$

right: $d_1 = \frac{3}{4}'' = 0.75''$, $d_2 = 1''$

$$\begin{aligned}\text{Value} &= 10^3 \times 10^{0.75''/1''}\\ &= 10^3 \times 5.623\\ &= \mathbf{5.623\ kHz}\end{aligned}$$

b. bottom: $d_1 = \frac{5}{16}'' = 0.3125''$, $d_2 = \frac{15}{16}'' = 0.9375''$

$$\begin{aligned}\text{Value} &= 10^{-1} \times 10^{0.3125''/0.9375''} = 10^{-1} \times 10^{0.333}\\ &= 10^{-1} \times 2.153\\ &= \mathbf{0.2153\ V}\end{aligned}$$

top: $d_1 = \frac{11}{16}'' = 0.6875''$, $d_2 = 0.9375''$

$$\begin{aligned}\text{Value} &= 10^{-1} \times 10^{0.6875''/0.9375''} = 10^{-1} \times 10^{0.720}\\ &= 10^{-1} \times 5.248\\ &= \mathbf{0.5248\ V}\end{aligned}$$

3. a. **1000** b. $\mathbf{10^{12}}$ c. **1.585** d. **1.096**

e. $\mathbf{10^{10}}$ f. **1513.56** g. **10.023** h. **1,258,925.41**

5. $\log_{10} 48 = \mathbf{1.681}$
$\log_{10} 8 + \log_{10} 6 = 0.903 + 0.778 = \mathbf{1.681}$

7. $\log_{10} 0.5 = \mathbf{-0.301}$
$-\log_{10} 2 = -(0.301) = \mathbf{-0.301}$

9. a. $\text{bels} = \log_{10} \frac{P_2}{P_1} = \log_{10} \frac{280\ \text{mW}}{4\ \text{mW}} = \log_{10} 70 = \mathbf{1.845}$

b. $\text{dB} = 10 \log_{10} \frac{P_2}{P_1} = 10(\log_{10} 70) = 10(1.845) = \mathbf{18.45}$

11. $\text{dB} = 10 \log_{10} \frac{P_2}{P_1} = 10 \log_{10} \frac{40\ \text{W}}{2\ \text{W}} = 10 \log_{10} 20 = \mathbf{13.01}$

13. $\text{dB}_v = 20 \log_{10} \frac{V_2}{V_1} = 20 \log_{10} \frac{8.4\ \text{V}}{0.1\ \text{V}} = 20 \log_{10} 84 = \mathbf{38.49}$

15. $\text{dB}_s = 20 \log_{10} \frac{P}{0.0002\ \mu\text{bar}}$

$\text{dB}_s = 20 \log_{10} \frac{0.001\ \mu\text{bar}}{0.0002\ \mu\text{bar}} = \mathbf{13.98}$

$$\text{dB}_s = 20 \log_{10} \frac{0.016\ \mu\text{bar}}{0.0002\ \mu\text{bar}} = \mathbf{38.06}$$

Increase = **24.08 dB$_s$**

19. a. $$A_v = \frac{\mathbf{V}_o}{\mathbf{V}_i} = \frac{X_C}{\sqrt{R^2 + X_C^2}} \angle -90° + \tan^{-1} X_C/R = \frac{1}{\sqrt{\left[\dfrac{R}{X_C}\right]^2 + 1}} \angle -\tan^{-1} R/X_C$$

$$f_c = \frac{1}{2\pi RC} = \frac{1}{2\pi(2.2\ \text{k}\Omega)(0.02\ \mu\text{F})} = \mathbf{3617.16\ Hz}$$

$f = f_c$: $\quad A_v = \dfrac{V_o}{V_i} = 0.707$

$f = 0.1f_c$: At f_c, $X_C = R = 2.2\ \text{k}\Omega$

$$X_C = \frac{1}{2\pi fC} = \frac{1}{2\pi\, 0.1 f_c C} = \frac{1}{0.1}\left[\frac{1}{2\pi f_c C}\right] = 10[2.2\ \text{k}\Omega] = 22\ \text{k}\Omega$$

$$A_v = \frac{1}{\sqrt{\left[\dfrac{R}{X_C}\right]^2 + 1}} = \frac{1}{\sqrt{\left[\dfrac{2.2\ \text{k}\Omega}{22\ \text{k}\Omega}\right]^2 + 1}} = \frac{1}{\sqrt{(.1)^2 + 1}} = \mathbf{0.995}$$

$f = 0.5f_c = \frac{1}{2}f_c$: $$X_C = \frac{1}{2\pi fC} = \frac{1}{2\pi\left[\dfrac{f_c}{2}\right]C} = 2\left[\frac{1}{2\pi f_c C}\right] = 2[2.2\ \text{k}\Omega] = 4.4\ \text{k}\Omega$$

$$A_v = \frac{1}{\sqrt{\left[\dfrac{2.2\ \text{k}\Omega}{4.4\ \text{k}\Omega}\right]^2 + 1}} = \frac{1}{\sqrt{(0.5)^2 + 1}} = \mathbf{0.894}$$

$f = 2f_c$: $$X_C = \frac{1}{2\pi(2f_c)C} = \frac{1}{2}\left[\frac{1}{2\pi f_c C}\right] = \frac{1}{2}[2.2\ \text{k}\Omega] = 1.1\ \text{k}\Omega$$

$$A_v = \frac{1}{\sqrt{\left[\dfrac{2.2\ \text{k}\Omega}{1.1\ \text{k}\Omega}\right]^2 + 1}} = \frac{1}{\sqrt{(2)^2 + 1}} = \mathbf{0.447}$$

$f = 10f_c$: $$X_C = \frac{1}{2\pi(10f_c)C} = \frac{1}{10}\left[\frac{1}{2\pi f_c C}\right] = \frac{1}{10}[2.2\ \text{k}\Omega] = 0.22\ \text{k}\Omega$$

$$A_v = \frac{1}{\sqrt{\left[\dfrac{2.2\ \text{k}\Omega}{0.22\ \text{k}\Omega}\right]^2 + 1}} = \frac{1}{\sqrt{(10)^2 + 1}} = \mathbf{0.0995}$$

b. $\theta = -\tan^{-1} R/X_C$

$f = f_c$: $\theta = -\tan^{-1} = \mathbf{-45°}$

$f = 0.1f_c$: $\theta = -\tan^{-1} 2.2\text{ k}\Omega/22\text{ k}\Omega = -\tan^{-1}\dfrac{1}{10} = \mathbf{-5.71°}$

$f = 0.5f_c$: $\theta = -\tan^{-1} 2.2\text{ k}\Omega/4.4\text{ k}\Omega = -\tan^{-1}\dfrac{1}{2} = \mathbf{-26.57°}$

$f = 2f_c$: $\theta = -\tan^{-1} 2.2\text{ k}\Omega/1.1\text{ k}\Omega = -\tan^{-1} 2 = \mathbf{-63.43°}$

$f = 10f_c$: $\theta = -\tan^{-1} 2.2\text{ k}\Omega/0.22\text{ k}\Omega = -\tan^{-1} 10 = \mathbf{-84.29°}$

21. $f_c = 500\text{ Hz} = \dfrac{1}{2\pi RC} = \dfrac{1}{2\pi(1.2\text{ k}\Omega)C}$

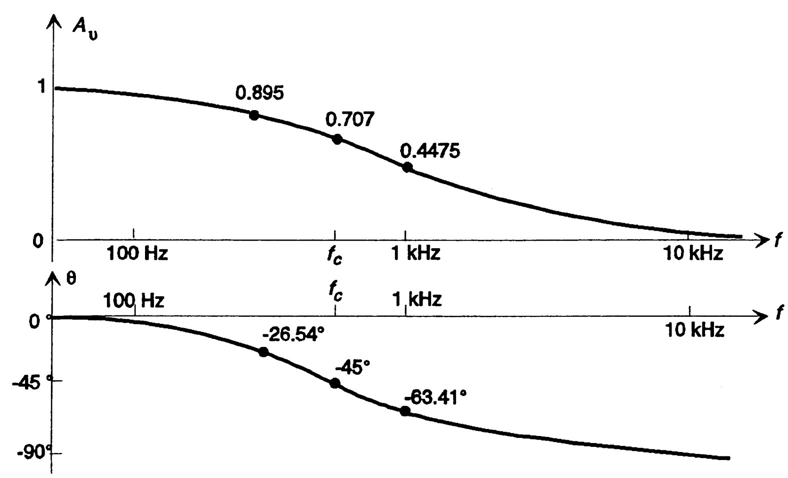
$$C = \frac{1}{2\pi Rf_c} = \frac{1}{2\pi(1.2\text{ k}\Omega)(500\text{ Hz})} = \mathbf{0.265\ \mu F}$$

$$A_v = \frac{V_o}{V_i} = \frac{1}{\sqrt{\left[\dfrac{R}{X_C}\right]^2 + 1}}$$

At $f = 250$ Hz, $X_C = 2402.33\ \Omega$ and $A_v = 0.895$
At $f = 1000$ Hz, $X_C = 600.58\ \Omega$ and $A_v = 0.4475$
$\theta = -\tan^{-1}R/X_C$

At $f = 250\text{ Hz} = \frac{1}{2}f_c$, $\theta = -26.54°$

At $f = 1\text{ kHz} = 2f_c$, $\theta = -63.41°$



23. a. $A_v = \dfrac{\mathbf{V}_o}{\mathbf{V}_i} = \dfrac{R}{\sqrt{R^2 + X_C^2}} \angle \tan^{-1} X_C/R = \dfrac{1}{\sqrt{1 + \left(\dfrac{X_C}{R}\right)^2}} \angle \tan^{-1} X_C/R$

$$f_c = \frac{1}{2\pi RC} = \frac{1}{2\pi(2.2\ \text{k}\Omega)(20\ \text{nF})} = \mathbf{3.617\ kHz}$$

$f = f_c$: $\quad A_v = \dfrac{V_o}{V_i} = 0.707$

$f = 2f_c$: $\quad$ At f_c, $X_C = R = 2.2\ \text{k}\Omega$

$$X_C = \frac{1}{2\pi fC} = \frac{1}{2\pi(2f_c)C} = \frac{1}{2}\left[\frac{1}{2\pi f_c C}\right] = \frac{1}{2}[2.2\ \text{k}\Omega] = 1.1\ \text{k}\Omega$$

$$A_v = \frac{1}{\sqrt{1 + \left[\dfrac{1.1\ \text{k}\Omega}{2.2\ \text{k}\Omega}\right]^2}} = \mathbf{0.894}$$

$f = \frac{1}{2}f_c$: $\quad X_C = \dfrac{1}{2\pi\left[\dfrac{f_c}{2}\right]C} = 2\left[\dfrac{1}{2\pi f_c C}\right] = 2[2.2\ \text{k}\Omega] = 4.4\ \text{k}\Omega$

$$A_v = \frac{1}{\sqrt{1 + \left[\dfrac{4.4\ \text{k}\Omega}{2.2\ \text{k}\Omega}\right]^2}} = \mathbf{0.447}$$

$f = 10f_c$: $\quad X_C = \dfrac{1}{2\pi(10f_c)C} = \dfrac{1}{10}\left[\dfrac{1}{2\pi f_c C}\right] = \dfrac{2.2\ \text{k}\Omega}{10} = 0.22\ \text{k}\Omega$

$$A_v = \frac{1}{\sqrt{1 + \left[\dfrac{0.22\ \text{k}\Omega}{2.2\ \text{k}\Omega}\right]^2}} = \mathbf{0.995}$$

$f = \frac{1}{10}f_c$: $\quad X_C = \dfrac{1}{2\pi\left[\dfrac{f_c}{10}\right]C} = 10\left[\dfrac{1}{2\pi f_c C}\right] = 10[2.2\ \text{k}\Omega] = 22\ \text{k}\Omega$

$$A_v = \frac{1}{\sqrt{1 + \left[\dfrac{22\ \text{k}\Omega}{2.2\ \text{k}\Omega}\right]^2}} = \mathbf{0.0995}$$

b. $f = f_c$, $\quad \theta = \mathbf{45^\circ}$

$f = 2f_c$, $\quad \theta = \tan^{-1}(X_C/R) = \tan^{-1} 1.1\ \text{k}\Omega/2.2\ \text{k}\Omega = \tan^{-1}\dfrac{1}{2} = \mathbf{26.57^\circ}$

$f = \frac{1}{2}f_c$, $\quad \theta = \tan^{-1}\dfrac{4.4\ \text{k}\Omega}{2.2\ \text{k}\Omega} = \tan^{-1} 2 = \mathbf{63.43^\circ}$

$f = 10f_c$, $\quad \theta = \tan^{-1}\dfrac{0.22\ \text{k}\Omega}{2.2\ \text{k}\Omega} = \mathbf{5.71^\circ}$

$f = \frac{1}{10}f_c$, $\quad \theta = \tan^{-1}\dfrac{22\ \text{k}\Omega}{2.2\ \text{k}\Omega} = \mathbf{84.29^\circ}$

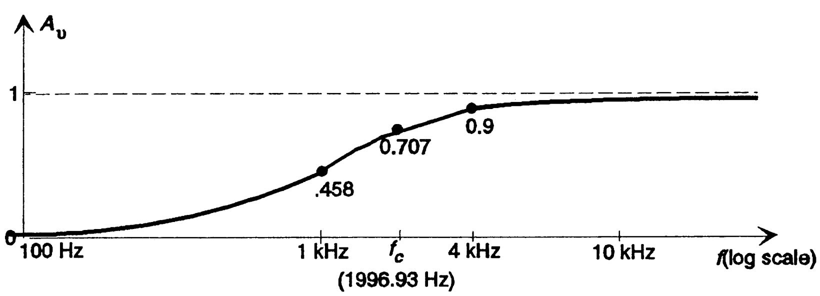
25. $\mathbf{A}_v = \dfrac{\mathbf{V}_o}{\mathbf{V}_i} = \dfrac{1}{\sqrt{1 + \left[\dfrac{X_C}{R}\right]^2}} \angle \tan^{-1} X_C/R$

$$f_c = \frac{1}{2\pi RC} \Rightarrow R = \frac{1}{2\pi f_c C} = \frac{1}{2\pi(2 \text{ kHz})(0.1\ \mu\text{F})} = 795.77\ \Omega$$

$$R = 795.77\ \Omega \Rightarrow \underbrace{750\ \Omega + 47\ \Omega}_{\text{nominal values}} = 797\ \Omega$$

$$\therefore f_c = \frac{1}{2\pi(797\ \Omega)(0.1\ \mu\text{F})} = \mathbf{1996.93\ Hz} \text{ using nominal values}$$

At $f = 1$ kHz, $A_v = 0.458$
$f = 4$ kHz, $A_v \cong 0.9$
$\theta = \tan^{-1} \dfrac{X_C}{R}$
$f = 1$ kHz, $\theta = 63.4°$
$f = 4$ kHz, $\theta = 26.53°$



27. a. low-pass section: $f_{c_1} = \dfrac{1}{2\pi RC} = \dfrac{1}{2\pi(0.1\ \text{k}\Omega)(2\ \mu\text{F})} = \mathbf{795.77\ Hz}$

high-pass section: $f_{c_2} = \dfrac{1}{2\pi RC} = \dfrac{1}{2\pi(10\ \text{k}\Omega)(8\ \text{nF})} = \mathbf{1989.44\ Hz}$

For the analysis to follow, it is assumed $(R_2 + jX_{C_2}) \| R_1 \cong R_1$ for all frequencies of interest.

At $f_{c_1} = 795.77$ Hz:

$V_{R_1} = 0.707\ V_i$

$X_{C_2} = \dfrac{1}{2\pi f C_2} = 25\ \text{k}\Omega$

$$|V_o| = \frac{25\ \text{k}\Omega(V_{R_1})}{\sqrt{(10\ \text{k}\Omega)^2 + (25\ \text{k}\Omega)^2}} = 0.9285\ V_{R_1}$$

$V_o = (0.9285)(0.707\ V_i) = \mathbf{0.656\ V_i}$

At $f_{c_2} = 1989.44$ Hz:

$$V_o = 0.707\ V_{R_1}$$

$$X_{C_1} = \frac{1}{2\pi f C_1} = 40\ \Omega$$

$$|V_{R_1}| = \frac{R_1 V_i}{\sqrt{R_1^2 + X_{C_1}^2}} = \frac{100\ \Omega(V_i)}{\sqrt{(100\ \Omega)^2 + (40\ \Omega)^2}} = 0.928\ V_i$$

$$|V_o| = (0.707)(0.928\ V_i) = \mathbf{0.656\ V_i}$$

At $f = 795.77\text{ Hz} + \dfrac{(1989.44\text{ Hz} - 795.77\text{ Hz})}{2} = 1392.60\text{ Hz}$

$$X_{C_1} = 57.14\ \Omega,\ X_{C_2} = 14.29\text{ k}\Omega$$

$$V_{R_1} = \frac{100\ \Omega(V_i)}{\sqrt{(100\ \Omega)^2 + (57.14\ \Omega)^2}} = 0.868\ V_i$$

$$V_o = \frac{14.29\text{ k}\Omega(V_{R_1})}{\sqrt{(10\text{ k}\Omega)^2 + (14.29\text{ k}\Omega)^2}} = 0.8193\ V_{R_1}$$

$$V_o = 0.8193(0.868\ V_i) = 0.711\ V_i$$

and $A_v = \dfrac{V_o}{V_i} = 0.711$ ($\cong$ maximum value)

After plotting the points it was determined that the gain should also be determined at $f = 500$ Hz and 4 kHz:

$f = 500$ Hz: $X_{C_1} = 159.15\ \Omega$, $X_{C_2} = 39.8\text{ k}\Omega$,
$V_{R_1} = 0.532\ V_i$, $V_o = 0.97\ V_{R_1}$
$V_o = \mathbf{0.516\ V_i}$

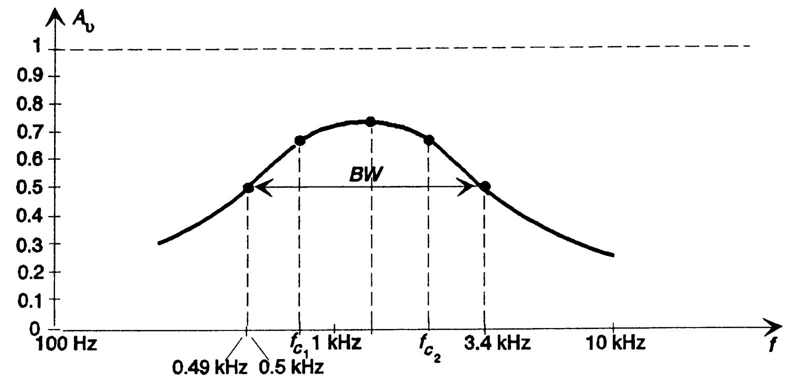
$f = 4$ kHz: $X_{C_1} = 19.89\ \Omega$, $X_{C_2} = 4.97\text{ k}\Omega$,
$V_{R_1} = 0.981\ V_i$, $V_o = 0.445\ V_{R_1}$
$V_o = \mathbf{0.437\ V_i}$

b. Using $0.707(.711) = 0.5026 \cong 0.5$ to define the bandwidth

$$BW = 3.4\text{ kHz} - 0.49\text{ kHz} = 2.91\text{ kHz}$$

and $BW \cong$ **2.9 kHz**

with $f_{\text{center}} = 490\text{ Hz} + \left[\dfrac{2.9\text{ kHz}}{2}\right] = \mathbf{1940\ Hz}$



29. a. $f_s = \dfrac{1}{2\pi\sqrt{LC}} = \dfrac{1}{2\pi\sqrt{(5\text{ mH})(500\text{ pF})}} = \mathbf{100.658\ kHz}$

b. $Q_s = \dfrac{X_L}{R + R_\ell} = \dfrac{2\pi(100.658\text{ kHz})(5\text{ mH})}{160\ \Omega + 12\ \Omega} = \mathbf{18.39}$

$BW = \dfrac{f_s}{Q_s} = \dfrac{100.658\text{ kHz}}{18.39} = \mathbf{5{,}473.52\ Hz}$

c. At $f = f_s$: $V_{o_{\max}} = \dfrac{R}{R + R_\ell}V_i = \dfrac{160\ \Omega(1\text{ V})}{172\ \Omega} = 0.93\text{ V}$ and $A_v = \dfrac{V_o}{V_i} = \mathbf{0.93}$

Since $Q_s \geq 10$, $f_1 = f_s - \dfrac{BW}{2} = 100.658\text{ kHz} - \dfrac{5{,}473.52\text{ Hz}}{2} = 97{,}921.24\text{ Hz}$

$f_2 = f_s + \dfrac{BW}{2} = 103{,}394.76\text{ Hz}$

At $f = 95$ kHz: $X_L = 2\pi fL = 2\pi(95 \times 10^3\text{ Hz})(5\text{ mH}) = 2.98\text{ k}\Omega$

$X_C = \dfrac{1}{2\pi fC} = \dfrac{1}{2\pi(95 \times 10^3\text{ Hz})(500\text{ pF})} = 3.35\text{ k}\Omega$

$\mathbf{V}_o = \dfrac{160\ \Omega(1\text{ V}\angle 0°)}{172 + j2.98\text{ k}\Omega - j3.35\text{ k}\Omega} = \dfrac{160\text{ V}\angle 0°}{172 - j370}$

$= \dfrac{160\text{ V}\angle 0°}{480\ \angle -65.07°} = \mathbf{0.392\ V\angle 65.07°}$

At $f = 105$ kHz: $X_L = 2\pi fL = 2\pi(105\text{ kHz})(5\text{ mH}) = 3.3\text{ k}\Omega$

$X_C = \dfrac{1}{2\pi fC} = \dfrac{1}{2\pi(105\text{ kHz})(500\text{ pF})} = 3.03\text{ k}\Omega$

$\mathbf{V}_o = \dfrac{160\ (1\text{ V}\ \angle 0°)}{172 + j3.3\text{ k}\Omega - j3.03\text{ k}\Omega} = \dfrac{160\text{ V}\angle 0°}{172 + j270}$

$= \dfrac{160\text{ V}\angle 0°}{320\ \angle 57.50°} = \mathbf{0.5\angle -57.50°}$

d. $f = f_s$: $V_{o_{\max}} = \mathbf{0.93\ V}$
$f = f_1 = 97{,}921.24\text{ Hz}$, $V_o = 0.707(0.93\text{ V}) = \mathbf{0.658\ V}$
$f = f_2 = 103{,}394.76\text{ Hz}$, $V_o = 0.707(0.93\text{ V}) = \mathbf{0.658\ V}$

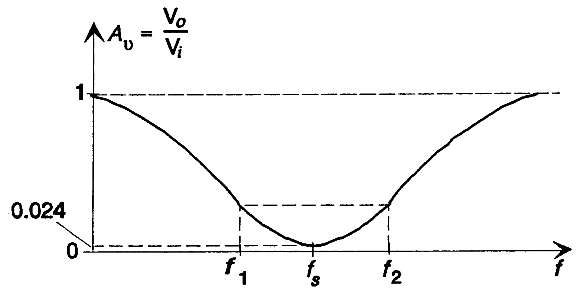
31. a. $Q_s = \dfrac{X_L}{R + R_\ell} = \dfrac{5000\ \Omega}{400\ \Omega + 10\ \Omega} = \dfrac{5000\ \Omega}{410\ \Omega} = \mathbf{12.195}$

b. $BW = \dfrac{f_s}{Q_s} = \dfrac{5000\text{ Hz}}{12.195} = \mathbf{410\ Hz}$

$f_1 = 5000\text{ Hz} - \dfrac{410\text{ Hz}}{2} = \mathbf{4795\ Hz}$

$f_2 = 5000\text{ Hz} + \dfrac{410\text{ Hz}}{2} = \mathbf{5205\ Hz}$

c.



At resonance

$V_o = \dfrac{10\ \Omega(V_i)}{10\ \Omega + 400\ \Omega}$
$= 0.024\ V_i$

d. At resonance, $10\ \Omega \| 2\text{ k}\Omega = 9.95\ \Omega$

$V_o = \dfrac{9.95\ \Omega(V_i)}{9.95\ \Omega + 400\ \Omega} \cong 0.024\ V_i$ as above!

33. a. $f_p = \dfrac{1}{2\pi\sqrt{LC}} = \dfrac{1}{2\pi\sqrt{(400\ \mu\text{H})(120\text{ pF})}} = \mathbf{726.44\ kHz}$ (band-stop)

$X_{L_s} \angle 90° + (X_{L_p} \angle 90° \| X_C \angle -90°) = 0$

$jX_{L_s} + \dfrac{(X_{L_p} \angle 90°)(X_C \angle -90°)}{jX_{L_p} - jX_C} = 0$

$jX_{L_s} + \dfrac{X_{L_p}X_C}{j(X_{L_p} - X_C)} = 0$

$jX_{L_s} - j\dfrac{X_{L_p}X_C}{(X_{L_p} - X_C)} = 0$

$X_{L_s} - \dfrac{X_{L_p}X_C}{X_{L_p} - X_C} = 0$

$X_{L_s}X_C - X_{L_s}X_{L_p} + X_{L_p}X_C = 0$

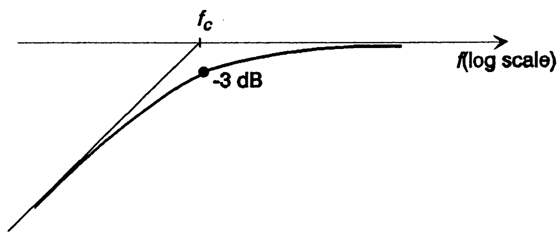
$\dfrac{\omega L_s}{\omega C} - \omega L_s \omega L_p + \dfrac{\omega L_p}{\omega C} = 0$

$$L_sL_p\omega^2 - \frac{1}{C}[L_s + L_p] = 0$$

$$\omega = \sqrt{\frac{L_s + L_p}{CL_sL_p}}$$

$$f = \frac{1}{2\pi}\sqrt{\frac{L_s + L_p}{CL_sL_p}} = \frac{1}{2\pi}\sqrt{\frac{460 \times 10^{-6}}{28.8 \times 10^{-19}}} = \mathbf{2.013\ MHz}\text{ (pass-band)}$$

35. a, b. $f_c = \dfrac{1}{2\pi RC} = \dfrac{1}{2\pi(0.47\ \text{k}\Omega)(0.05\ \mu\text{F})} = \mathbf{772.55\ Hz}$



c. $f = \frac{1}{2}f_c$: $A_{v_{dB}} = 20\log_{10}\dfrac{1}{\sqrt{1 + (f_c/f)^2}} = 20\log_{10}\dfrac{1}{\sqrt{1 + (2)^2}} = \mathbf{-7\ dB}$

$f = 2f_c$: $A_{v_{dB}} = 20\log_{10}\dfrac{1}{\sqrt{1 + (0.5)^2}} = \mathbf{-0.969\ dB}$

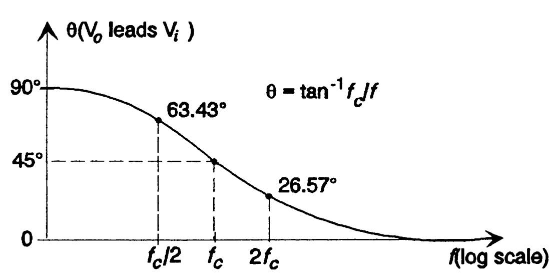
$f = \frac{1}{10}f_c$: $A_{v_{dB}} = 20\log_{10}\dfrac{1}{\sqrt{1 + (10)^2}} = \mathbf{-20.04\ dB}$

$f = 10f_c$: $A_{v_{dB}} = 20\log_{10}\dfrac{1}{\sqrt{1 + (0.1)^2}} = \mathbf{-0.043\ dB}$

d. $f = \frac{1}{2}f_c$: $A_v = \dfrac{1}{\sqrt{1 + (f_c/f)^2}} = \dfrac{1}{\sqrt{1 + (2)^2}} = \mathbf{0.4472}$

$f = 2f_c$: $A_v = \dfrac{1}{\sqrt{1 + (0.5)^2}} = \mathbf{0.894}$

e.



37. a, b. $\mathbf{A}_v = \dfrac{\mathbf{V}_o}{\mathbf{V}_i} = A_v \angle\theta = \dfrac{1}{\sqrt{1 + (f/f_c)^2}} \angle -\tan^{-1} f/f_c$

$$f_c = \frac{1}{2\pi RC} = \frac{1}{2\pi(12\text{ k}\Omega)(1\text{ nF})} = 13.26\text{ kHz}$$

c. $f = f_c/2 = 6.63$ kHz

$$A_{v_{dB}} = 20\log_{10}\frac{1}{\sqrt{1 + (0.5)^2}} = \mathbf{-0.97\ dB}$$

$f = 2f_c = 26.52$ kHz

$$A_{v_{dB}} = 20\log_{10}\frac{1}{\sqrt{1 + (2)^2}} = \mathbf{-6.99\ dB}$$

$f = f_c/10 = 1.326$ kHz

$$A_{v_{dB}} = 20\log_{10}\frac{1}{\sqrt{1 + (0.1)^2}} = \mathbf{-0.043\ dB}$$

$f = 10f_c = 132.6$ kHz

$$A_{v_{dB}} = 20\log_{10}\frac{1}{\sqrt{1 + (10)^2}} = \mathbf{-20.04\ dB}$$

d. $f = f_c/2$: $\quad A_v = \dfrac{1}{\sqrt{1 + (0.5)^2}} = \mathbf{0.894}$

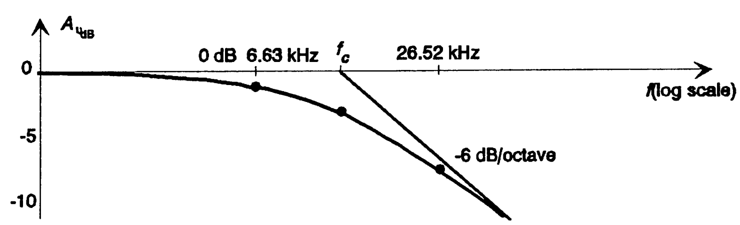
$f = 2f_c$: $\quad A_v = \dfrac{1}{\sqrt{1 + (2)^2}} = \mathbf{0.447}$

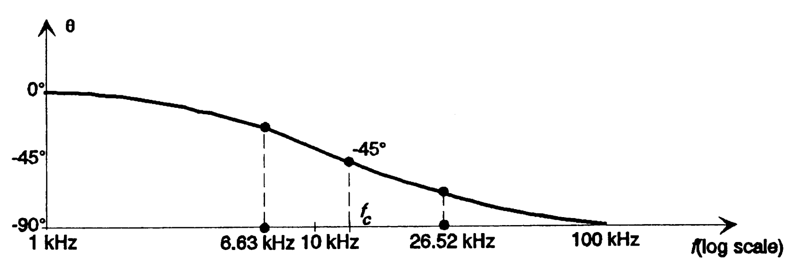
e. $\theta = \tan^{-1} f/f_c$

$f = f_c/2$: $\quad \theta = -\tan^{-1} 0.5 = -26.57°$

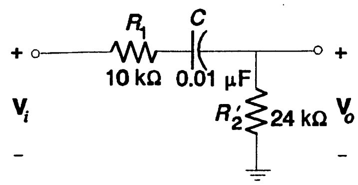
$f = f_c$: $\quad \theta = -\tan^{-1} 1 = -45°$

$f = 2f_c$: $\quad \theta = -\tan^{-1} 2 = -63.43°$





39.

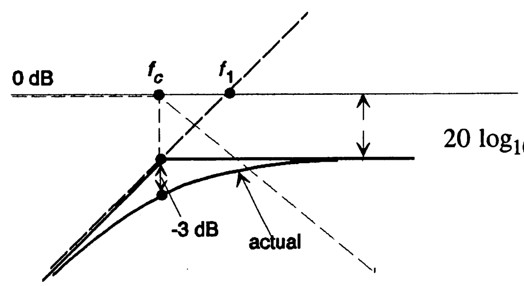


a. From Section 23.11,

$$\mathbf{A}_v = \frac{\mathbf{V}_o}{\mathbf{V}_i} = \frac{jf/f_1}{1 + jf/f_c}$$

$$f_1 = \frac{1}{2\pi R_2' C} = \frac{1}{2\pi(24\text{ k}\Omega)(0.01\ \mu\text{F})} = 663.15\text{ Hz}$$

$$f_c = \frac{1}{2\pi(R_1 + R_2')C} = \frac{1}{2\pi(10\text{ k}\Omega + 24\text{ k}\Omega)(0.01\ \mu\text{F})} = 468.1\text{ Hz}$$



$$20\log_{10}\frac{f}{f_1} = 20\log_{10}\frac{f_c}{f_1} = 20\log_{10}\frac{468.1\text{ Hz}}{663.15\text{ Hz}} = \mathbf{-3.03\ dB}$$

b. $\theta = 90° - \tan^{-1}\dfrac{f}{f_1} = +\tan^{-1}\dfrac{f_1}{f}$

$f = f_1$: $\theta = 45°$

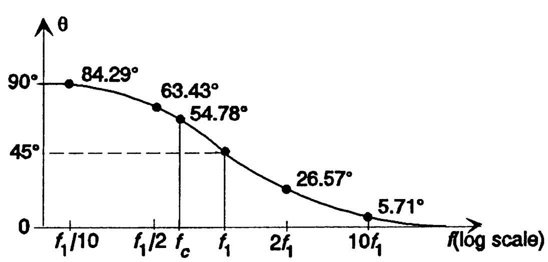
$f = f_c$: $\theta = 54.78°$

$f = \frac{1}{2}f_1 = 331.58\text{ Hz},\ \theta = 63.43°$

$f = \frac{1}{10}f_1 = 66.31\text{ Hz},\ \theta = 84.29°$

$f = 2f_1 = 1{,}326.3\text{ Hz},\ \theta = 26.57°$

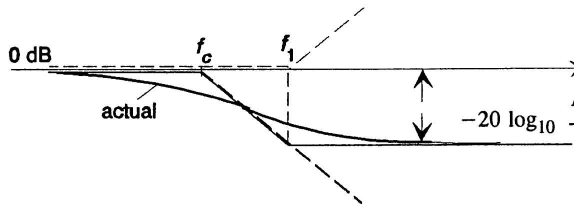
$f = 10f_1 = 6{,}631.5\text{ Hz},\ \theta = 5.71°$



41. a. $\mathbf{A}_v = \dfrac{1 + j\dfrac{f}{f_1}}{1 + j\dfrac{f}{f_c}}$

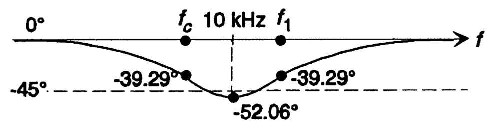
$f_1 = \dfrac{1}{2\pi R_2 C} = \dfrac{1}{2\pi(10\text{ k}\Omega)(800\text{ pF})} = 19{,}894.37\text{ Hz}$

$f_c = \dfrac{1}{2\pi(R_1 + R_2)C} = \dfrac{1}{2\pi(10\text{ k}\Omega + 90\text{ k}\Omega))(800\text{ pF})}$
$= 1{,}989.44\text{ Hz}$



$-20\log_{10}\dfrac{R_1 + R_2}{R_2} = -20\log_{10} 10$
$= \mathbf{-20\ dB}$

b.



$\theta = \tan^{-1} f/f_1 - \tan^{-1} f/f_c$

$f = 10\text{ kHz}$

$\theta = \tan^{-1}\dfrac{10\text{ kHz}}{19.89\text{ kHz}} - \tan^{-1}\dfrac{10\text{ kHz}}{1.989\text{ kHz}} = 26.69° - 78.75° = \mathbf{-52.06°}$

$f = f_c$: $(f_1 = 10 f_c)$

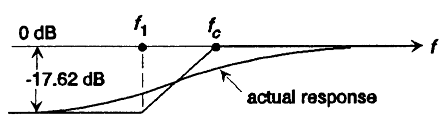
$\theta = \tan^{-1}\dfrac{f_c}{10 f_c} - \tan^{-1}\dfrac{f_c}{f_c} = \tan^{-1} 0.1 - \tan^{-1} 1 = 5.71° - 45° = \mathbf{-39.29°}$

43. a. $\mathbf{A}_v = \dfrac{\mathbf{V}_o}{\mathbf{V}_i} = \dfrac{1 - j f_1/f}{1 - j f_c/f}$

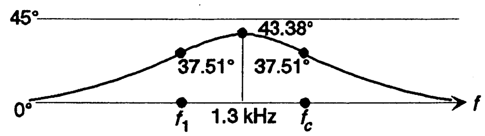
$f_1 = \dfrac{1}{2\pi R_1 C} = \dfrac{1}{2\pi(3.3\text{ k}\Omega)(0.05\ \mu\text{F})} = 964.58\text{ Hz}$

$f_c = \dfrac{1}{2\pi(R_1 \| R_2)C} = \dfrac{1}{2\pi\underbrace{(3.3\text{ k}\Omega \| 0.5\text{ k}\Omega)}_{0.434\text{ k}\Omega}(0.05\ \mu\text{F})} = \mathbf{7{,}334.33\ Hz}$

$-20\log_{10}\dfrac{R_1 + R_2}{R_2} = -20\log_{10}\dfrac{3.3\text{ k}\Omega + 0.5\text{ k}\Omega}{0.5\text{ k}\Omega} = -20\log_{10} 7.6 = -17.62\text{ dB}$



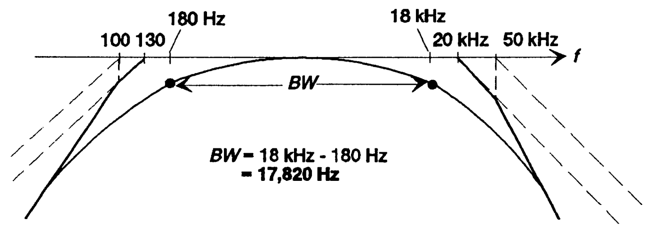
b.



$$\theta = -\tan^{-1}\frac{f_1}{f} + \tan^{-1}\frac{f_c}{f}$$

$f = 1.3$ kHz: $$\theta = -\tan^{-1}\frac{964.58 \text{ kHz}}{1.3 \text{ kHz}} + \tan^{-1}\frac{7334.33 \text{ Hz}}{1.3 \text{ kHz}}$$
$$= -36.57° + 79.95° = 43.38°$$

45. a. $$\frac{A_v}{A_{v_{\max}}} = \frac{1}{\left[1 - j\dfrac{100 \text{ Hz}}{f}\right]\left[1 - j\dfrac{130 \text{ Hz}}{f}\right]\left[1 + j\dfrac{f}{20 \text{ kHz}}\right]\left[1 + j\dfrac{f}{50 \text{ kHz}}\right]}$$



Proximity of 100 Hz to 130 Hz will raise lower cutoff frequency above 130 Hz:

Testing: $f = 180$ Hz: (with lower terms only)

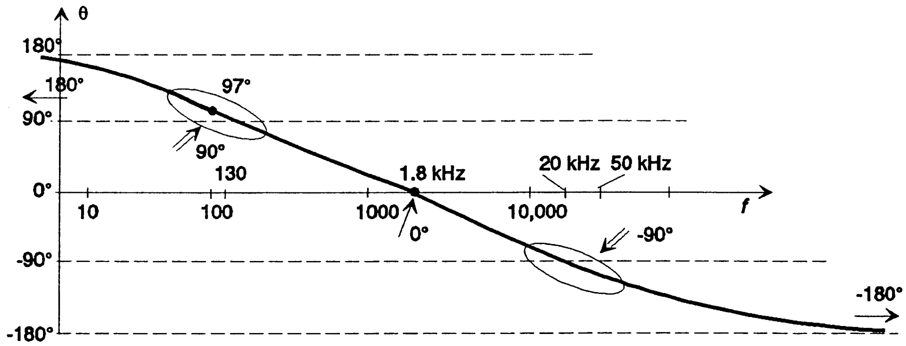
$$A_{v_{\text{dB}}} = -20 \log_{10}\sqrt{1 + \left[\frac{100}{f}\right]^2} - 20 \log_{10}\sqrt{1 + \left[\frac{130}{f}\right]^2}$$
$$= -20 \log_{10}\sqrt{1 + \left[\frac{100}{180}\right]^2} - 20 \log_{10}\sqrt{1 + \left[\frac{130}{180}\right]^2}$$
$$= 1.17 \text{ dB} - 1.82 \text{ dB} = \mathbf{-2.99 \text{ dB}} \cong -3 \text{ dB}$$

Proximity of 50 kHz to 20 kHz will lower high cutoff frequency below 20 kHz:

Testing: $f = 18$ kHz: (with upper terms only)

$$A_{v_{\text{dB}}} = -20 \log_{10}\sqrt{1 + \left[\frac{f}{20 \text{ kHz}}\right]^2} - 20 \log_{10}\sqrt{1 + \left[\frac{f}{50 \text{ kHz}}\right]^2}$$
$$= -20 \log_{10}\sqrt{1 + \left[\frac{18 \text{ kHz}}{20 \text{ kHz}}\right]^2} - 20 \log_{10}\sqrt{1 + \left[\frac{13 \text{ kHz}}{20 \text{ kHz}}\right]^2}$$
$$= -2.576 \text{ dB} - 0.529 \text{ dB} = \mathbf{-3.105 \text{ dB}}$$

b.

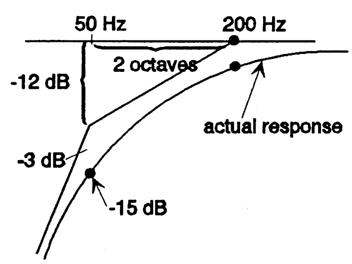


Testing: $f = 1.8$ kHz:

$$\theta = \tan^{-1}\frac{100}{1.8\text{ kHz}} + \tan^{-1}\frac{130}{1.8\text{ kHz}} - \tan^{-1}\frac{1.8\text{ kHz}}{20\text{ kHz}} - \tan^{-1}\frac{1.8\text{ kHz}}{50\text{ kHz}}$$
$$= 3.18° + 4.14° - 5.14° - 2.06°$$
$$= \mathbf{0.12° \cong 0°}$$

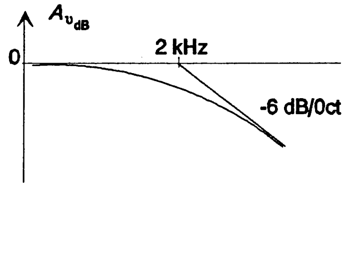
47. $f_{\text{low}} = f_{\text{high}} - BW = 36\text{ kHz} - 35.8\text{ kHz} = 0.2\text{ kHz} = 200\text{ Hz}$

$$A_v = \frac{-120}{\left(1 - j\frac{50}{f}\right)\left(1 - j\frac{200}{f}\right)\left(1 + j\frac{f}{36\text{ kHz}}\right)}$$



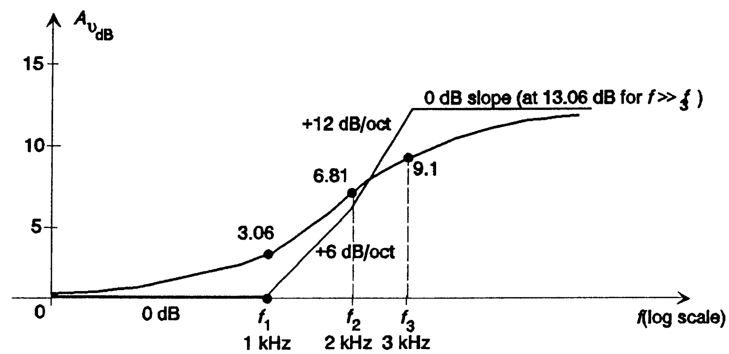
49. $$\mathbf{A}_v = \frac{200}{200 + j0.1f} = \frac{1}{1 + j\frac{0.1f}{200}} = \frac{1}{1 + j\frac{f}{2000}}$$

$$A_{v_{\text{dB}}} = 20\log_{20}\frac{1}{\sqrt{1 + \left(\frac{f}{2000}\right)^2}},\quad \frac{f}{2000} = 1 \text{ and } f = \mathbf{2\text{ kHz}}$$



51. $A_v = \dfrac{\left[1 + j\dfrac{f}{1000}\right]\left[1 + j\dfrac{f}{2000}\right]}{\left[1 + j\dfrac{f}{3000}\right]^2}$

$$A_{v_{dB}} = 20\log_{10}\sqrt{1 + \left[\frac{f_1}{1000}\right]^2} + 20\log_{10}\sqrt{1 + \left[\frac{f_2}{2000}\right]^2} + 40\log_{10}\frac{1}{\sqrt{1 + \left[\dfrac{f_3}{3000}\right]^2}}$$



53. a. woofer - 400 Hz:

$$X_L = 2\pi fL = 2\pi(400\text{ Hz})(4.7\text{ mH}) = 11.81\ \Omega$$

$$X_C = \frac{1}{2\pi fC} = \frac{1}{2\pi(400\text{ Hz})(39\ \mu\text{F})} = 10.20\ \Omega$$

$$R\|X_C = 8\ \Omega\ \angle 0^\circ \| 10.20\angle -90^\circ = 6.3\ \Omega\ \angle -38.11^\circ$$

$$\mathbf{V}_o = \frac{(R\|X_C)(\mathbf{V}_i)}{(R\|X_C) + jX_L} = \frac{(6.3\ \Omega\ \angle -38.11^\circ)(\mathbf{V}_i)}{(6.3\ \Omega\ \angle -38.11^\circ) + j11.81\ \Omega}$$

$$\mathbf{V}_o = 0.673\ \angle -96.11^\circ\ \mathbf{V}_i$$

and $A_v = \dfrac{V_o}{V_i} =$ **0.673** vs desired 0.707 (off by less than 5%)

tweeter - 5 kHz:

$$X_L = 2\pi fL = 2\pi(5\text{ kHz})(0.39\text{ mH}) = 12.25\ \Omega$$

$$X_C = \frac{1}{2\pi fC} = \frac{1}{2\pi(5\text{ kHz})(2.7\ \mu\text{F})} = 11.79\ \Omega$$

$$R\|X_L = 8\ \Omega\ \angle 0^\circ \| 12.25\ \Omega\ \angle 90^\circ = 6.7\ \Omega\ \angle 33.15^\circ$$

$$\mathbf{V}_o = \frac{(6.7\ \Omega\ \angle 33.15^\circ)(\mathbf{V}_i)}{(6.7\ \Omega\ \angle 33.15^\circ) - j11.79\ \Omega}$$

$$\mathbf{V}_o = 0.678\ \angle 88.54^\circ\ \mathbf{V}_i$$

and $A_v = \dfrac{V_o}{V_i} =$ **0.678** vs 0.707 (off by less than 5%)

b. woofer - 3 kHz:

$$X_L = 2\pi fL = 2\pi(3\text{ kHz})(4.7\text{ mH}) = 88.59\ \Omega$$

$$X_C = \frac{1}{2\pi fC} = \frac{1}{2\pi(3\text{ kHz})(39\ \mu\text{F})} = 1.36\ \Omega$$

$$R \| X_C = 8\ \Omega\ \angle 0° \| 1.36\ \Omega\ \angle -90° = 1.341\ \Omega\ \angle -80.35°$$

$$\mathbf{V}_o = \frac{(R\|X_C)(\mathbf{V}_i)}{(R\|X_C) + jX_L} = \frac{(1.341\ \Omega\ \angle\text{-}80.35°)(\mathbf{V}_i)}{(1.341\ \Omega\ \angle\text{-}80.35°) + j88.59\ \Omega}$$

$$\mathbf{V}_o = 0.015\ \angle -170.2°\ \mathbf{V}_i$$

and $A_v = \dfrac{V_o}{V_i}$ = **0.015** vs desired 0 (excellent)

tweeter - 3 kHz:

$$X_L = 2\pi fL = 2\pi(3\text{ kHz})(0.39\text{ mH}) = 7.35\ \Omega$$

$$X_C = \frac{1}{2\pi fC} = \frac{1}{2\pi(3\text{ kHz})(2.7\ \mu\text{F})} = 19.65\ \Omega$$

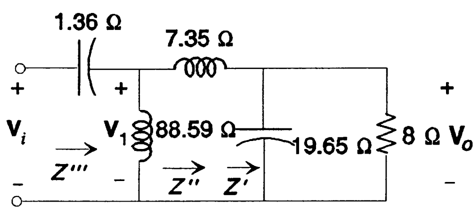
$$R \| X_L = 8\ \Omega\ \angle 0° \| 7.35\ \Omega\ \angle 90° = 5.42\ \Omega\ \angle 47.42°$$

$$\mathbf{V}_o = \frac{(R\|X_L)(\mathbf{V}_i)}{(R\|X_L) + jX_C} = \frac{(5.42\ \Omega\ \angle 47.42°)(\mathbf{V}_i)}{(5.42\ \Omega\ \angle 47.42°) - j19.65\ \Omega}$$

$$\mathbf{V}_o = 0.337\ \angle 124.24°\ \mathbf{V}_i$$

and $A_v = \dfrac{V_o}{V_i}$ = **0.337** (acceptable since relatively close to cutoff frequency for tweeter)

c. mid-range speaker - 3 kHz:



$$\mathbf{Z}' = 7.41\ \Omega\ \angle -22.15°$$

$$\mathbf{Z}' = 8.24\ \Omega\ \angle 33.58°$$

$$\mathbf{Z}''' = 7.816\ \Omega\ \angle 37.79°$$

$$\mathbf{V}_1 = \frac{\mathbf{Z}'''\mathbf{V}_i}{\mathbf{Z}''' - jX_C} = \frac{(7.816\ \Omega\ \angle 37.79°)\mathbf{V}_i}{7.816\ \Omega\ \angle 37.79° - j1.36\ \Omega} = 1.11\ \angle 8.83°\ \mathbf{V}_i$$

$$\mathbf{V}_o = \frac{\mathbf{Z}'\mathbf{V}_1}{\mathbf{Z}' + jX_L} = \frac{(7.41\ \Omega\ \angle\text{-}22.15°)\mathbf{V}_i}{7.41\ \Omega\ \angle -22.15° + j7.35\ \Omega} = 0.998\ \angle -46.9°\ \mathbf{V}_i$$

and $A_v = \dfrac{V_o}{V_i}$ = **0.998** kHz (excellent)

CHAPTER 23 (Even)

2.	a.	**5**	b.	**−4**	c.	**8**	d.	**−6**
	e.	**1.301**	f.	**3.937**	g.	**4.748**	h.	**−0.498**
4.	a.	**11.513**	b.	**−9.21**	c.	**2.996**	d.	**9.065**

6. $\log_{10} 0.2 = \mathbf{-0.699}$
$\log_{10} 18 - \log_{10} 90 = 1.255 - 1.954 = \mathbf{-0.699}$

8. $\log_{10} 27 = \mathbf{1.431}$
$3 \log_{10} 3 = 3(0.4771) = \mathbf{1.431}$

10.
$$\text{dB} = 10 \log_{10} \frac{P_2}{P_1}$$
$$6 \text{ dB} = 10 \log_{10} \frac{100 \text{ W}}{P_1}$$
$$0.6 = \log_{10} x$$
$$x = 3.981 = \frac{100 \text{ W}}{P_1}$$
$$P_1 = \frac{100 \text{ W}}{3.981} = \mathbf{25.12\ W}$$

12.
$$\text{dB}_m = 10 \log_{10} \frac{P}{1 \text{ mW}}$$
$$\text{dB}_m = 10 \log_{10} \frac{120 \text{ mW}}{1 \text{ mW}} = 10 \log_{10} 120 = \mathbf{20.792}$$

14.
$$\text{dB}_v = 20 \log_{10} \frac{V_2}{V_1}$$
$$22 = 20 \log_{10} \frac{V_o}{20 \text{ mV}}$$
$$1.1 = \log_{10} x$$
$$x = 12.589 = \frac{V_o}{20 \text{ mV}}$$
$$V_o = \mathbf{251.785\ mV}$$

16. $60 \text{ dB}_s \Rightarrow 90 \text{ dB}_s$
quiet loud

$$60 \text{ dB}_s = 20 \log_{10} \frac{P_1}{0.002\ \mu\text{bar}} = 20 \log_{10} x$$
$$3 = \log_{10} x$$
$$x = \mathbf{1000}$$

$$90\ \text{dB}_s = 20\log_{10}\frac{P_2}{0.002\ \mu\text{bar}} = 20\log_{10}y$$
$$4.5 = \log_{10}y$$
$$y = \mathbf{31.623 \times 10^3}$$
$$\frac{x}{y} = \frac{\dfrac{P_1}{0.002\ \cancel{\mu\text{bar}}}}{\dfrac{P_2}{0.002\ \cancel{\mu\text{bar}}}} = \frac{P_1}{P_2} = \frac{\cancel{10^3}}{31.623 \times \cancel{10^3}}$$
and $P_2 = \mathbf{31.623\ P_1}$

18. a.
$$8\ \text{dB} = 20\log_{10}\frac{V_2}{0.775\ \text{V}}$$
$$0.4 = \log_{10}\frac{V_2}{0.775\ \text{V}}$$
$$\frac{V_2}{0.775\ \text{V}} = 2.512$$
$$V_2 = (2.512)(0.775\ \text{V}) = 1.947\ \text{V}$$
$$P = \frac{V^2}{R} = \frac{(1.947\ \text{V})^2}{600\ \Omega} = \mathbf{6.318\ mW}$$

b.
$$-5\ \text{dB} = 20\log_{10}\frac{V_2}{0.775\ \text{V}}$$
$$-0.25 = \log_{10}\frac{V_2}{0.775\ \text{V}}$$
$$\frac{V_2}{0.775\ \text{V}} = 0.562$$
$$V_2 = (0.562)(0.775\ \text{V}) = 0.436\ \text{V}$$
$$P = \frac{V^2}{R} = \frac{(0.436\ \text{V})^2}{600\ \Omega} = \mathbf{0.317\ mW}$$

20. a.
$$f_c = \frac{1}{2\pi RC} = \frac{1}{2\pi(1\ \text{k}\Omega)(0.01\ \mu\text{F})} = 15.915\ \text{kHz}$$
$$f = 2f_c = 31.83\ \text{kHz}$$
$$X_C = \frac{1}{2\pi fC} = \frac{1}{2\pi(31.83\ \text{kHz})(0.01\ \mu\text{F})} = 500\ \Omega$$
$$A_v = \frac{V_o}{V_i} = \frac{X_C}{\sqrt{R^2 + X_C^2}} = \frac{500\ \Omega}{\sqrt{(1\ \text{k}\Omega)^2 + (0.5\ \text{k}\Omega)^2}} = 0.4472$$
$$V_o = 0.4472V_i = 0.4472(10\ \text{mV}) = \mathbf{4.472\ mV}$$

b.
$$f = \frac{1}{10}f_c = \frac{1}{10}(15{,}915\ \text{kHz}) = 1.5915\ \text{kHz}$$
$$X_C = \frac{1}{2\pi fC} = \frac{1}{2\pi(1.5915\ \text{kHz})(0.01\ \mu\text{F})} = 10\ \text{k}\Omega$$
$$A_v = \frac{V_o}{V_i} = \frac{X_C}{\sqrt{R^2 + X_C^2}} = \frac{10\ \text{k}\Omega}{\sqrt{(1\ \text{k}\Omega)^2 + (10\ \text{k}\Omega)^2}} = 0.995$$
$$V_o = 0.995V_i = 0.995(10\ \text{mV}) = \mathbf{9.95\ mV}$$

c. Yes, at $f = f_c$, $V_o = 7.07$ mV

at $f = \frac{1}{10}f_c$, $V_o = 9.95$ mV (much higher)

at $f = 2f_c$, $V_o = 4.472$ mV (much lower)

22. a. $f_c = \dfrac{1}{2\pi RC} = \dfrac{1}{2\pi(4.7\text{ k}\Omega)(500\text{ pF})} = \mathbf{67.726\ kHz}$

b. $f = 0.1 f_c = 0.1(67.726\text{ kHz}) \cong 6.773\text{ kHz}$

$$X_C = \frac{1}{2\pi fC} = \frac{1}{2\pi(6.773\text{ kHz})(500\text{ pF})} = 46.997\text{ k}\Omega$$

$$A_v = \frac{V_o}{V_i} = \frac{X_C}{\sqrt{R^2 + X_C^2}} = \frac{46.997\text{ k}\Omega}{\sqrt{(4.7\text{ k}\Omega)^2 + (46.997\text{ k}\Omega)^2}} = \mathbf{0.995} \cong 1$$

c. $f = 10f_c = 677.26$ kHz

$$X_C = \frac{1}{2\pi fC} = \frac{1}{2\pi(677.26\text{ kHz})(500\text{ pF})} \cong 470\ \Omega$$

$$A_v = \frac{V_o}{V_i} = \frac{X_C}{\sqrt{R^2 + X_C^2}} = \frac{470\ \Omega}{\sqrt{(4.7\text{ k}\Omega)^2 + (470\ \Omega)^2}} = \mathbf{0.0995} \cong 0.1$$

d. $$A_v = \frac{V_o}{V_i} = 0.01 = \frac{X_C}{\sqrt{R^2 + X_C^2}}$$

$$\sqrt{R^2 + X_C^2} = \frac{X_C}{0.01} = 100\,X_C$$

$$R^2 + X_C^2 = 10^4 X_C^2$$

$$R^2 = 10^4 X_C^2 - X_C^2 = 9{,}999 X_C^2$$

$$X_C = \frac{R}{\sqrt{9{,}999}} = \frac{4.7\text{ k}\Omega}{99.995} \cong 47\ \Omega$$

$$X_C = \frac{1}{2\pi fC} \Rightarrow f = \frac{1}{2\pi X_C C} = \frac{1}{2\pi(47\ \Omega)(500\text{ pF})} = \mathbf{6.77\ MHz}$$

24. a. $f = f_c$: $A_v = \dfrac{V_o}{V_i} = \mathbf{0.707}$

b. $f_c = \dfrac{1}{2\pi RC} = \dfrac{1}{2\pi(10\text{ k}\Omega)(1000\text{ pF})} = 15.915\text{ kHz}$

$f = 4f_c = 4(15.915\text{ kHz}) = 63.66\text{ kHz}$

$$X_C = \frac{1}{2\pi fC} = \frac{1}{2\pi(63.66\text{ kHz})(1000\text{ pF})} = 2.5\text{ k}\Omega$$

$$A_v = \frac{V_o}{V_i} = \frac{R}{\sqrt{R^2 + X_C^2}} = \frac{10\text{ k}\Omega}{\sqrt{(10\text{ k}\Omega)^2 + (2.5\text{ k}\Omega)^2}} = \mathbf{0.970}\text{ (significant rise)}$$

c. $f = 100f_c = 100(15.915 \text{ kHz}) = 1591.5 \text{ kHz} \cong 1.592 \text{ MHz}$

$$X_C = \frac{1}{2\pi fC} = \frac{1}{2\pi(1.592 \text{ MHz})(1000 \text{ pF})} = 99.972 \ \Omega$$

$$A_v = \frac{R}{\sqrt{R^2 + X_C^2}} = \frac{10 \text{ k}\Omega}{\sqrt{(10 \text{ k}\Omega)^2 + (99.972 \ \Omega)^2}} = 0.99995 \cong 1$$

d. At $f = f_c$, $V_o = 0.707V_i = 0.707(10 \text{ mV}) = 7.07 \text{ mV}$

$$P_o = \frac{V_o^2}{R} = \frac{(7.07 \text{ mV})^2}{10 \text{ k}\Omega} \cong \mathbf{5\ nW}$$

26. a. $$f_c = \frac{1}{2\pi RC} = \frac{1}{2\pi(100 \text{ k}\Omega)(20 \text{ pF})} = \mathbf{79.577\ kHz}$$

b. $f = 0.01f_c = 0.01(79.577 \text{ kHz}) = 0.7958 \text{ kHz} \cong 796 \text{ Hz}$

$$X_C = \frac{1}{2\pi fC} = \frac{1}{2\pi(796 \text{ Hz})(20 \text{ pF})} = 9.997 \text{ M}\Omega$$

$$A_v = \frac{V_o}{V_i} = \frac{R}{\sqrt{R^2 + X_C^2}} = \frac{100 \text{ k}\Omega}{\sqrt{(100 \text{ k}\Omega)^2 + (9.997 \text{ M}\Omega)^2}} = \mathbf{0.01} \cong 0$$

c. $f = 100f_c = 100(79.577 \text{ kHz}) \cong 7.96 \text{ MHz}$

$$X_C = \frac{1}{2\pi fC} = \frac{1}{2\pi(7.96 \text{ MHz})(20 \text{ pF})} = 999.72 \ \Omega$$

$$A_v = \frac{V_o}{V_i} = \frac{R}{\sqrt{R^2 + X_C^2}} = \frac{100 \text{ k}\Omega}{\sqrt{(100 \text{ k}\Omega)^2 + (999.72 \ \Omega)^2}} = \mathbf{0.99995} \cong 1$$

d. $$A_v = \frac{V_o}{V_i} = 0.5 = \frac{R}{\sqrt{R^2 + X_C^2}}$$

$$\sqrt{R^2 + X_C^2} = 2R$$

$$R^2 + X_C^2 = 4R^2$$

$$X_C^2 = 4R^2 - R^2 = 3R^2$$

$$X_C = \sqrt{3R^2} = \sqrt{3}R = \sqrt{3}(100 \text{ k}\Omega) = 173.2 \text{ k}\Omega$$

$$X_C = \frac{1}{2\pi fC} \Rightarrow f = \frac{1}{2\pi X_C C} = \frac{1}{2\pi(173.2 \text{ k}\Omega)(20 \text{ pF})}$$

$$f = \mathbf{45.95\ kHz}$$

28. $$f_1 = \frac{1}{2\pi R_1 C_1} = 4 \text{ kHz}$$

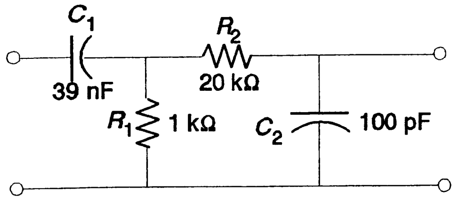
Choose $R_1 = 1 \text{ k}\Omega$

$$C_1 = \frac{1}{2\pi f_1 R_1} = \frac{1}{2\pi(4 \text{ kHz})(1 \text{ k}\Omega)} = 39.8 \text{ nF} \therefore \text{Use } \mathbf{39\ nF}$$

$$f_2 = \frac{1}{2\pi R_2 C_2} = 80 \text{ kHz}$$

Choose $R_2 = 20 \text{ k}\Omega$

$$C_2 = \frac{1}{2\pi f_2 R_2} = \frac{1}{2\pi(80 \text{ kHz})(20 \text{ k}\Omega)} = 99.47 \text{ pF} \therefore \text{Use } 100 \text{ pF}$$



$$\text{Center frequency} = 4 \text{ kHz} + \frac{80 \text{ kHz} - 4 \text{ kHz}}{2} = 42 \text{ kHz}$$

At $f = 42$ kHz, $X_{C_1} = 97.16\ \Omega$, $X_{C_2} = 37.89 \text{ k}\Omega$

Assuming $\mathbf{Z}_2 \gg \mathbf{Z}_1$

$$|V_{R_1}| = \frac{R_1(V_i)}{\sqrt{R_1^2 + X_{C_1}^2}} = 0.995V_i$$

$$|V_o| = \frac{X_{C_2}(V_{R_1})}{\sqrt{R_2^2 + X_{C_2}^2}} = 0.884V_i$$

$V_o = 0.884V_{R_1} = 0.884(0.995V_i) = \mathbf{0.88}\ \boldsymbol{V_i}$

as $f = f_1$: $V_{R_1} = 0.707V_i$, $X_{C_2} = 221.05 \text{ k}\Omega$

and $V_o = 0.996V_{R_1}$

so that $V_o = 0.996V_{R_1} = 0.996(0.707V_i) = 0.704V_i$

Although $A_v = 0.88$ is less than the desired level of 1, f_1 and f_2 do define a band of frequencies for which $A_v \geq 0.7$ and the power to the load is significant.

30. a. $$f_p = \frac{1}{2\pi\sqrt{LC}}\sqrt{1 - \frac{R_\ell^2 C}{L}} \cong \mathbf{159.15\ kHz}$$

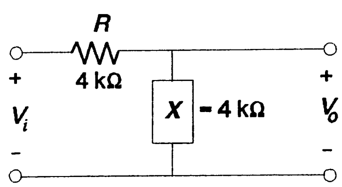
$$Q_\ell = \frac{X_L}{R_\ell} = \frac{2\pi f_p L}{R_\ell} = \frac{2\pi(159.15 \text{ kHz})(1 \text{ mH})}{16\ \Omega} = 62.5 \gg 10$$

$\therefore Z_{T_p} = Q_\ell^2 R_\ell = (62.5)^2\ 16\ \Omega = 62.5 \text{ k}\Omega \gg R = 4 \text{ k}\Omega$

and $V_o \cong V_i$ at resonance.

However, $R = 4 \text{ k}\Omega$ affects the shape of the resonance curve and $BW = f_p/Q_\ell$ cannot be applied.

For $A_v = \dfrac{V_o}{V_i} = 0.707$, $|X| = R$ for the following configuration



For frequencies near f_p, $X_L >> R_\ell$ and $Z_L = R_\ell + jX_L \cong X_L$ and $X = X_L \| X_C$.

For frequencies near f_p but less than f_p

$$X = \frac{X_C X_L}{X_C - X_L}$$

and for $A_v = 0.707$

$$\frac{X_C X_L}{X_C - X_L} = R$$

Substituting $X_C = \frac{1}{2\pi f_1 C}$ and $X_L = 2\pi f_1 L$

the following equation can be derived:

$$f_1^2 + \frac{1}{2\pi RC} f_1 - \frac{1}{4\pi^2 LC} = 0$$

For this situation:

$$\frac{1}{2\pi RC} = \frac{1}{2\pi(4\ \text{k}\Omega)(0.001\ \mu\text{F})} = 39.79 \times 10^3$$

$$\frac{1}{4\pi^2 LC} = \frac{1}{4\pi^2(1\ \text{mH})(0.001\ \mu\text{F})} = 2.53 \times 10^{10}$$

and solving the quadratic equation, $f_1 = 140.4$ kHz

and $\frac{BW}{2} = 159.15\ \text{kHz} - 140.4\ \text{kHz} = 18.75\ \text{kHz}$

with $BW = 2(18.75\ \text{kHz}) = \mathbf{37.5\ kHz}$

b. $Q_p = \frac{f_p}{BW} = \frac{159.15\ \text{kHz}}{37.5\ \text{kHz}} = \mathbf{4.24}$

32. a. $Q_\ell = \frac{X_L}{R_\ell} = \frac{400\ \Omega}{10\ \Omega} = 40$

$$Z_{T_p} = Q_\ell^2 R_\ell = (40)^2\ 20\ \Omega = 32\ \text{k}\Omega >> 1\ \text{k}\Omega$$

At resonance, $V_o = \frac{32\ \text{k}\Omega\ V_i}{32\ \text{k}\Omega + 1\ \text{k}\Omega} = 0.97V_i$

and $A_v = \frac{V_o}{V_i} = 0.97$

For the low cutoff frequency note solution to Problem 30:

$$f_1^2 + \frac{1}{2\pi f R_C} f_1 - \frac{1}{4\pi^2 LC} = 0$$

$$C = \frac{1}{2\pi f X_C} = \frac{1}{2\pi(20\ \text{kHz})(400\ \Omega)} = 19.9\ \text{nF}$$

$$L = \frac{X_L}{2\pi f} = \frac{400\ \Omega}{2\pi(20\ \text{kHz})} = 3.18\ \text{mH}$$

Substituting into the above equation and solving

$$f_1 = 16.4 \text{ kHz}$$

with $\frac{BW}{2} = 20 \text{ kHz} - 16.4 \text{ kHz} = 3.6 \text{ kHz}$

and $BW = 2(3.6 \text{ kHz}) = \mathbf{7.2 \text{ kHz}}$

$$Q_p = \frac{f_p}{BW} = \frac{20 \text{ kHz}}{7.2 \text{ kHz}} = \mathbf{2.78}$$

b. —

c. At resonance

$$Z_{T_p} = 32 \text{ k}\Omega \parallel 100 \text{ k}\Omega = 24.24 \text{ k}\Omega$$

$$\text{with } V_o = \frac{24.24 \text{ k}\Omega \; V_i}{24.24 \text{ k}\Omega + 1 \text{ k}\Omega} = 0.96V_i$$

$$\text{and } A_v = \frac{V_o}{V_i} = 0.96 \text{ vs } 0.97 \text{ above}$$

At frequencies to the right and left of f_p, the impedance Z_{T_p} will decrease and be affected less and less by the parallel 100 kΩ load. The characteristics, therefore, are only slightly affected by the 100 kΩ load.

d. At resonance

$$Z_{T_p} = 32 \text{ k}\Omega \parallel 20 \text{ k}\Omega = 12.31 \text{ k}\Omega$$

$$\text{with } V_o = \frac{12.31 \text{ k}\Omega \; V_i}{12.31 \text{ k}\Omega + 1 \text{ k}\Omega} = 0.925V_i \text{ vs } 0.97 \text{ above}$$

At frequencies to the right and left of f_p, the impedance of each frequency will actually be less due to the parallel 20 kΩ load. The effect will be to narrow the resonance curve and decrease the bandwidth with an increase in Q_p.

34. a.

$$f_s = \frac{1}{2\pi\sqrt{LC}} \Rightarrow L_s = \frac{1}{4\pi^2 f_s^2 C} = \frac{1}{4\pi^2(100 \text{ kHz})^2(200 \text{ pF})} = 12.68 \text{ mH}$$

$$X_L = 2\pi fL = 2\pi(30 \text{ kHz})(12.68 \text{ mH}) = 2388.91 \; \Omega$$

$$X_C = \frac{1}{2\pi fC} = \frac{1}{2\pi(30 \text{ kHz})(200 \text{ pF})} = 26.54 \text{ k}\Omega$$

$$X_C - X_L = 26.54 \text{ k}\Omega - 2388.91 \; \Omega = 24.15 \text{ k}\Omega(C)$$

$$X_{L_p} = X_{C_{(\text{net})}} = 24.15 \text{ k}\Omega$$

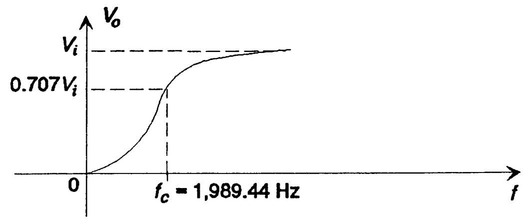
$$L_p = \frac{X_L}{2\pi f} = \frac{24.15 \text{ k}\Omega}{2\pi(30 \text{ kHz})} = \mathbf{128.19 \text{ mH}}$$

36. a.

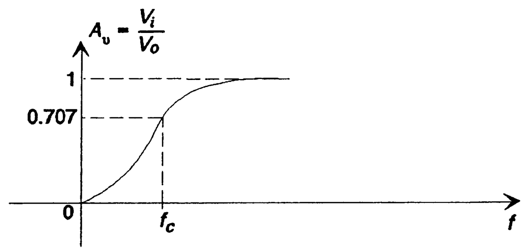
$$f_c = \frac{1}{2\pi RC} = \frac{1}{2\pi(6 \text{ k}\Omega \parallel 12 \text{ k}\Omega)0.01 \; \mu\text{F}} = \frac{1}{2\pi(4 \text{ k}\Omega)(0.01 \; \mu\text{F})} = \mathbf{1989.44 \text{ Hz}}$$

$$\frac{V_o}{V_i} = \frac{1}{\sqrt{1 + (f_c/f)^2}}$$

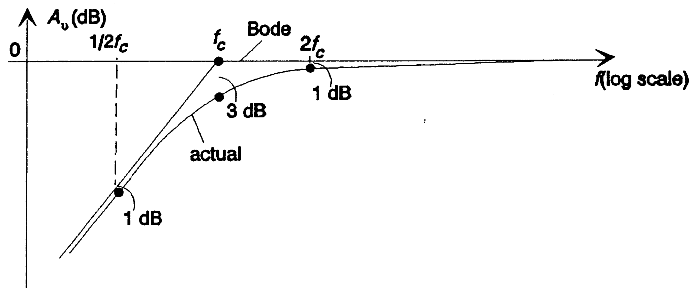
$$\text{and } V_o = \left[\frac{1}{\sqrt{1 + (f_c/f)^2}}\right] V_i$$



b.



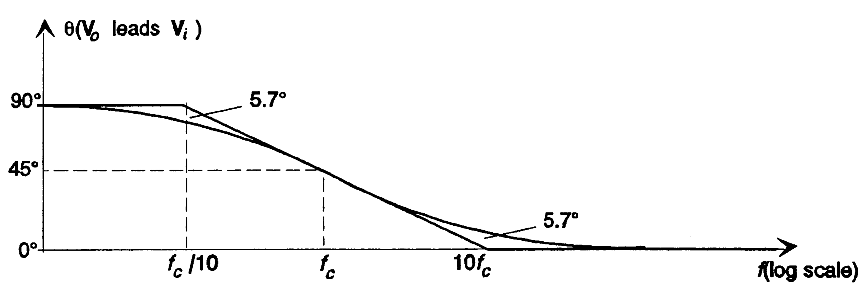
c. & d.



e. Remember the log scale! $1.5f_c$ not midway between f_c and $2f_c$

$$
\begin{aligned}
A_{v_{\text{dB}}} &= 20 \log_{10} A_v \\
-1.5 &= 20 \log_{10} A_v \\
-0.075 &= \log_{10} A_v \\
A_v &= \frac{V_o}{V_i} = \mathbf{0.841}
\end{aligned}
$$

f. $\theta = \tan^{-1} f_c/f$



38. a. $R_2 \| X_C = \dfrac{(R_2)(-jX_C)}{R_2 - jX_C} = -j\dfrac{R_2X_C}{R_2 - jX_C}$

$$\mathbf{V}_o = \frac{\left[\dfrac{-jR_2X_C)}{R_2 - jX_C}\right]\mathbf{V}_i}{R_1 - j\dfrac{R_2X_C}{R_2 - jX_C}} = -j\frac{R_2X_C\mathbf{V}_i}{R_1(R_2 - jX_C) - jR_2X_C}$$

$$= \frac{-jR_2X_C\mathbf{V}_i}{R_1R_2 - jR_1X_C - jR_2X_C} = \frac{-jR_2X_C\mathbf{V}_i}{R_1R_2 - j(R_1 + R_2)X_C}$$

$$= \frac{R_2X_C\mathbf{V}_i}{jR_1R_2 + (R_1 + R_2)X_C} = \frac{R_2\mathbf{V}_i}{j\dfrac{R_1R_2}{X_C} + (R_1 + R_2)}$$

$$= \frac{R_2\mathbf{V}_i}{R_1 + R_2 + j\dfrac{R_1R_2}{X_C}} = \frac{\left[\dfrac{R_2}{R_1 + R_2}\right]\mathbf{V}_i}{1 + j\left[\dfrac{R_1R_2}{R_1 + R_2}\right]\dfrac{1}{X_C}}$$

and $\mathbf{A}_v = \dfrac{\mathbf{V}_o}{\mathbf{V}_i} = \dfrac{\dfrac{R_2}{R_1 + R_2}}{1 + j\omega\left[\dfrac{R_1R_2}{R_1 + R_2}\right]C}$

or $\mathbf{A}_v = \dfrac{R_2}{R_1 + R_2}\left[\dfrac{1}{1 + j2\pi f(R_1 \| R_2)C}\right]$

defining $f_c = \dfrac{1}{2\pi(R_1 \| R_2)C}$

$$\mathbf{A}_v = \frac{R_2}{R_1 + R_2}\left[\frac{1}{1 + j\, f/f_c}\right]$$

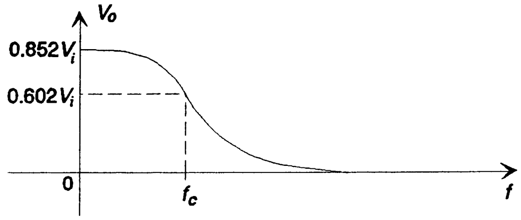
and $\mathbf{A}_v = \dfrac{R_2}{R_1 + R_2}\left[\dfrac{1}{\sqrt{1 + (f/f_c)^2}} \angle -\tan^{-1} f/f_c\right]$

with $|V_o| = \dfrac{R_2}{R_1 + R_2}\left[\dfrac{1}{\sqrt{1 + (f/f_c)^2}}\right]|V_i|$

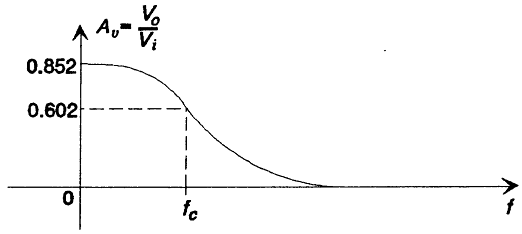
for $f \ll f_c$, $V_o = \dfrac{R_2}{R_1 + R_2}V_i = \dfrac{27\text{ k}\Omega}{4.7\text{ k}\Omega + 27\text{ k}\Omega}V_i = 0.852V_i$

at $f = f_c$: $V_o = 0.852[0.707]V_i = 0.602V_i$

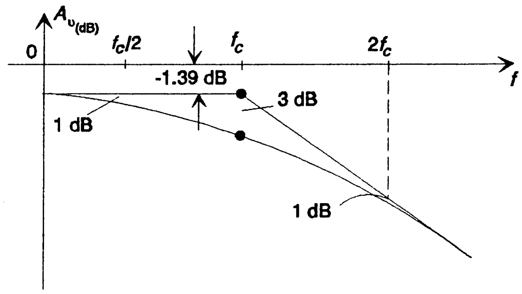
$f_c = \dfrac{1}{2\pi(R_1 \| R_2)C}$ = **994.72 Hz**



b.



c. & d.

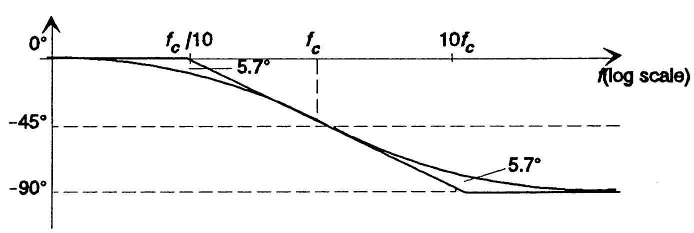


$$-20 \log_{10} \frac{R_1 + R_2}{R_2} = -20 \log_{10} \frac{4.7\text{ k}\Omega + 27\text{ k}\Omega}{27\text{ k}\Omega}$$
$$= -20 \log_{10} 1.174 = -1.39\text{ dB}$$

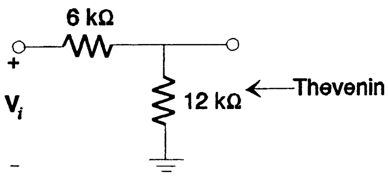
e. $A_{v_{\text{dB}}} \cong -1.39\text{ dB} - 0.5\text{ dB} = -1.89\text{ dB}$

$$A_{v_{\text{dB}}} = 20 \log_{10} A_v$$
$$-1.89 = 20 \log_{10} A_v$$
$$0.0945 = \log_{10} A_v$$
$$A_v = \frac{V_o}{V_i} = \mathbf{0.804}$$

f. $\theta = -\tan^{-1} f/f_c$

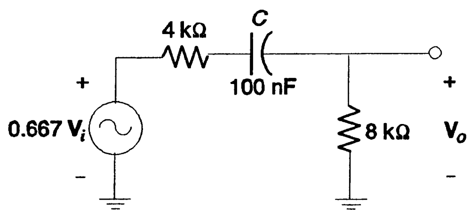


40. a.



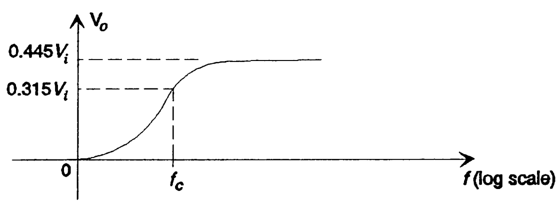
$$\mathbf{V}_{Th} = \frac{12\text{ k}\Omega\ \mathbf{V}_i}{12\text{ k}\Omega + 6\text{ k}\Omega} = 0.667\ \mathbf{V}_i$$

$$R_{Th} = 6\text{ k}\Omega \parallel 12\text{ k}\Omega = 4\text{ k}\Omega$$



$f = \infty$ Hz: ($C \Rightarrow$ short circuit)

$$\mathbf{V}_o = \frac{8\text{ k}\Omega\ (0.667\ \mathbf{V}_i)}{8\text{ k}\Omega + 4\text{ k}\Omega} = 0.445\ \mathbf{V}_i$$



voltage-divider rule: $\mathbf{V}_o = \dfrac{R_2(0.667\ \mathbf{V}_i)}{R_1 + R_2 - jX_C} = \dfrac{0.667\ R_2\mathbf{V}_i}{R_1 + R_2 - jX_C}$

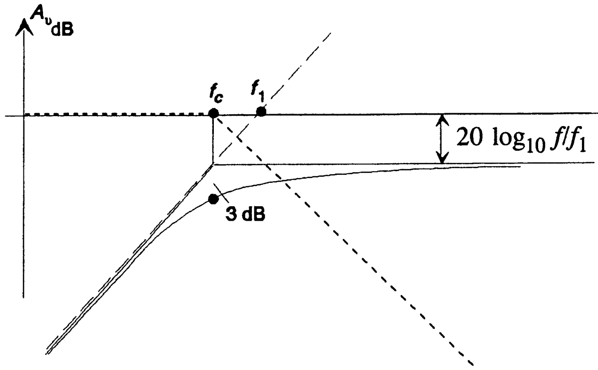
and $\mathbf{A}_v = \dfrac{\mathbf{V}_o}{\mathbf{V}_i} = \dfrac{0.667R_2}{R_1 + R_2 - jX_C} = \dfrac{j2\pi f(0.667R_2)C}{1 + j2\pi f(R_1 + R_2)C}$

so that $\mathbf{A}_v = \dfrac{jf/f_1}{1 + jf/f_c}$ with $f_1 = \dfrac{1}{2\pi 0.667R_2C} = \dfrac{1}{2\pi 0.667(8\text{ k}\Omega)(100\text{ nF})}$

$= 298.27$ Hz

and $f_c = \dfrac{1}{2\pi(R_1 + R_2)C} = \dfrac{1}{2\pi(4\text{ k}\Omega + 8\text{ k}\Omega)(100\text{ nF})}$

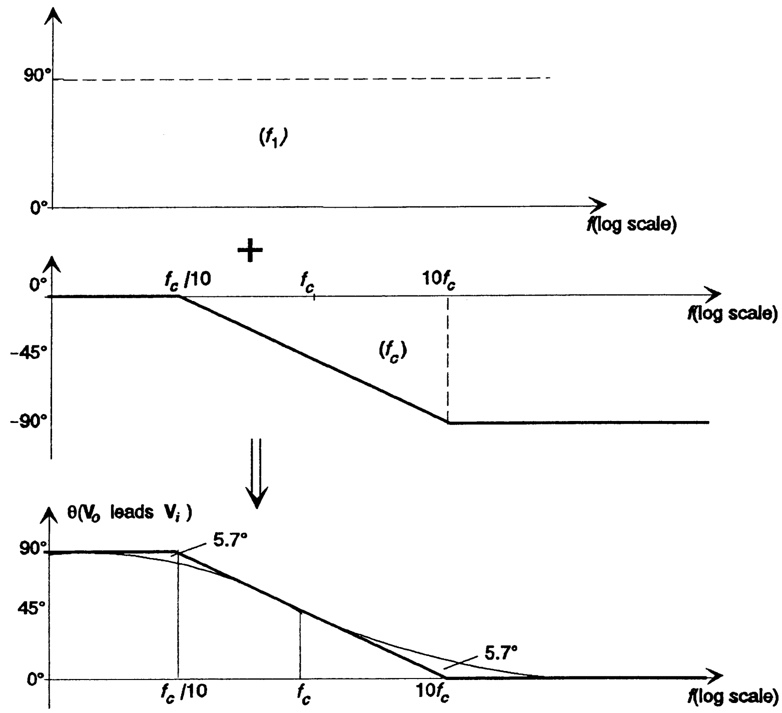
$= 132.63$ Hz



$$20 \log_{10} f/f_1 = 20 \log_{10} \frac{132.63 \text{ Hz}}{298.27 \text{ Hz}}$$
$$= 20 \log_{10} 0.445 = -7.04 \text{ dB}$$

b. $\theta = 90° - \tan^{-1} f/f_c = +\tan^{-1} f_c/f = \tan^{-1} 132.6 \text{ Hz}/f$

or



42. a. R_1 no effect!
Note Section 23.12.

$$\mathbf{A}_v = \frac{\mathbf{V}_o}{\mathbf{V}_i} = \frac{1 + j\,(f/f_1)}{1 + j\,(f/f_c)}$$

$$f_1 = \frac{1}{2\pi(6 \text{ k}\Omega)(0.01 \ \mu\text{F})} = 2652.58 \text{ Hz}$$

$$f_c = \frac{1}{2\pi(12 \text{ k}\Omega + 6 \text{ k}\Omega)(0.01 \ \mu\text{F})} = 884.19 \text{ Hz}$$

Note Fig. 23.65.

Asymptote at 0 dB from $0 \to f_c$

-6 dB/octave from f_c to f_1

-9.54 dB from f_1 on $\left[-20 \log \dfrac{12\text{ k}\Omega + 6\text{ k}\Omega}{6\text{ k}\Omega} = -9.54\text{ dB}\right]$

(b) Note Fig. 23.67.

From 0° to $-26.50°$ at f_c and f_1

$\theta = \tan^{-1} f/f_1 - \tan^{-1} f/f_c$

At $f = 1500$ Hz (between f_c and f_1)

$\theta = \tan^{-1} 1500\text{ Hz}/2652.58\text{ Hz} - \tan^{-1} 1500\text{ Hz}/884.19\text{ Hz}$

$= 29.49° - 59.48° = -30°$

44. a. Note Section 23.13.

$$\mathbf{A}_v = \frac{1 - j(f_1/f)}{1 - j(f_c/f)}$$

$$f_1 = \frac{1}{2\pi R_1 C} = \frac{1}{2\pi(3.3\text{ k}\Omega)(0.05\ \mu\text{F})} = \mathbf{964.58\ Hz}$$

$$f_c = \frac{1}{2\pi(R_1 \| R_2)C} = \frac{1}{2\pi\underbrace{(3.3\text{ k}\Omega \| 0.5\text{ k}\Omega)}_{0.434\text{ k}\Omega}0.05\ \mu\text{F}} = \mathbf{7334.33\ Hz}$$

Note Fig. 23.72.

$$-20 \log_{10} \frac{R_1 + R_2}{R_2} = -20 \log_{10} \frac{3.3\text{ k}\Omega + 0.5\text{ k}\Omega}{0.5\text{ k}\Omega} = -17.62\text{ dB}$$

Asymptote at -17.62 dB from $0 \to f_1$

$+6$ dB/octave from f_1 to f_c

0 dB from f_c on

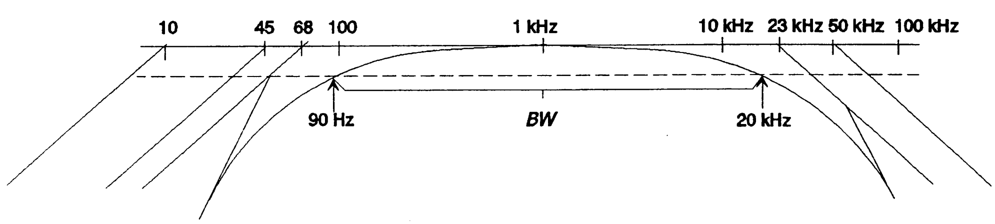
b. $\theta = -\tan^{-1} f_1/f + \tan^{-1} f_c/f$

Test at 3 kHz

$\theta = -\tan^{-1} 964.58\text{ Hz}/3.0\text{ kHz} + \tan^{-1} 7334.33\text{ Hz}/3.0\text{ kHz}$

$= -17.82° + 67.75° = 49.93° \cong 50°$

Therefore rising above 45° at and near the peak



50 kHz vs 23 kHz $\to$ drop about 1 dB at 23 kHz due to 50 kHz break.

Ignore effect of break frequency at 10 Hz.

Assume -2 dB drop at 68 Hz due to break frequency at 45 Hz.

Rough sketch suggests low cut-off frequency of 90 Hz.

Checking: Ignoring upper terms

$$A'_{v_{dB}} = -20\ \log_{10}\sqrt{1 + \left(\frac{10\text{ Hz}}{f}\right)^2} - 20\log_{10}\sqrt{1 + \left(\frac{45\text{ Hz}}{f}\right)^2} - 20\log_{10}\sqrt{1 + \left(\frac{68\text{ Hz}}{f}\right)^2}$$

$$= -0.0532\text{ dB} - 0.969\text{ dB} - 1.96\text{ dB}$$

$$= -2.98\text{ dB} \quad \text{(excellent)}$$

High frequency cutoff: Try 20 kHz

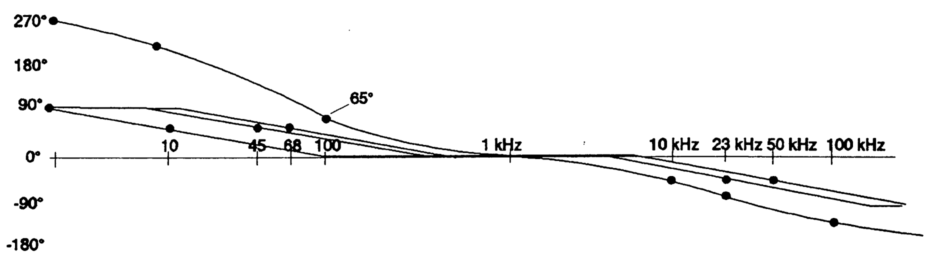
$$A'_{v_{dB}} = -20\log_{10}\sqrt{1 + \left(\frac{f}{23\text{ kHz}}\right)^2} - 20\ \log_{10}\sqrt{1 + \left(\frac{f}{50\text{ kHz}}\right)^2}$$

$$= -2.445\text{ dB} - 0.6445\text{ dB}$$

$$= -3.09\text{ dB} \quad \text{(excellent)}$$

$\therefore BW = 20\text{ kHz} - 90\text{ kHz} = \mathbf{19{,}910\ Hz} \cong 20\text{ kHz}$

$f_1 = \mathbf{90\ Hz}, f_2 = \mathbf{20\ kHz}$



Testing: $f = 100$ Hz

$$\theta = \tan^{-1}\frac{10\text{ Hz}}{f} + \tan^{-1}\frac{45\text{ Hz}}{f} + \tan^{-1}\frac{68\text{ Hz}}{f} - \tan^{-1}\frac{f}{23\text{ kHz}} - \tan^{-1}\frac{f}{50\text{ kHz}}$$

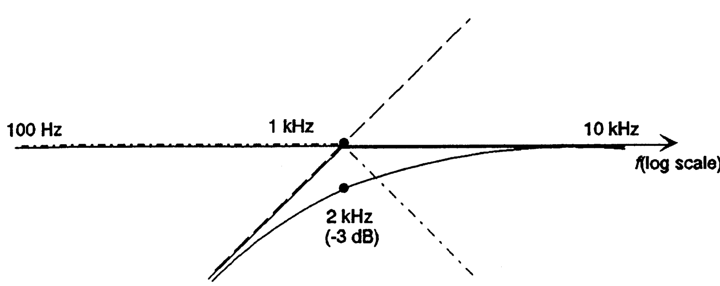
$$= \tan^{-1} 0.1 + \tan^{-1} 0.45 + \tan^{-1} 0.68 - \tan^{-1} 0.00435 - \tan^{-1} .002$$

$$= 5.71° + 24.23° + 34.22° - 0.249° - 0.115°$$

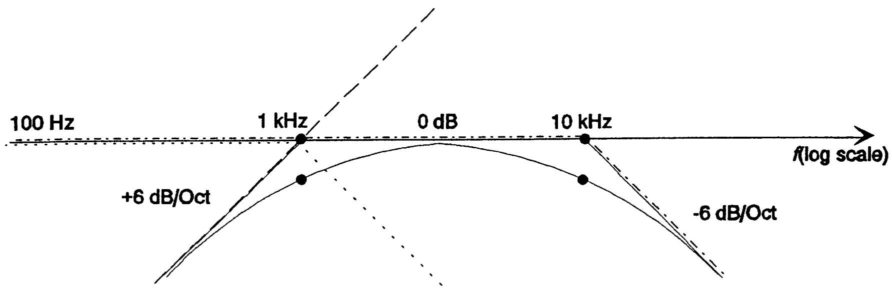
$= \mathbf{63.8}°$ vs about 65° on the plot

48. $$\mathbf{A}_v = \frac{0.05}{0.05 - j\dfrac{100}{f}} = \frac{1}{1 - j\dfrac{100}{0.05 f}} = \frac{1}{1 - j\dfrac{2000}{f}} = \frac{+jf}{+jf + 2000}$$

$$= \frac{+j\dfrac{f}{2000}}{1 + j\dfrac{f}{2000}} \text{ and } f_1 = 2000\text{ Hz}$$



50. $\mathbf{A}_v = \dfrac{jf/1000}{(1 + jf/1000)(1 + jf/10{,}000)}$



52. $\dfrac{j\omega}{1000} = j\dfrac{2\pi f}{1000} = j\dfrac{f}{\dfrac{1000}{2\pi}} = j\dfrac{f}{159.16\ \text{Hz}}, \quad \dfrac{j\omega}{5000} = j\dfrac{f}{795.78\ \text{Hz}}$